

Mitigation of Rayleigh crosstalk using noise suppression technique in 10-Gb/s REAM-SOA

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Abstract: We demonstrate a mitigation of Rayleigh back-scattering (RBS) impact in 10-Gb/s reflective electroabsorption modulator monolithically integrated with semiconductor optical amplifier (REAM-SOA). The technique is based on the intensity-noise suppression of the centralized incoherent seed-light, which enables smooth evolution of deployed DWDM applications. We exhibit the power penalty of less than 1 dB at the large RBS crosstalk value of about 8 dB when the optical power of seed-light is lowered about -10 dBm.

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References and links

1. M. J. Wale, "Options and trends for PON tunable optical transceivers," in *European Conference and Exhibition on Optical Communication (ECOC)*, (2011), Paper Mo.2.C.1.
2. C. Kazmierski, "Remote amplified modulators: key components for 10 Gb/s WDM PON," in *Optical Fiber Communication Conference (OFC)*, (2010), paper OVN6.
3. N. Dupuis, J. Decobert, C. Jany, F. Alexandre, A. Garreau, N. Lagay, F. Martin, D. Carpentier, J. Landreau, and C. Kazmierski, "10-Gb/s AlGaInAs colorless remote amplified modulator by selective area growth for wavelength agnostic networks," *IEEE Photon. Technol. Lett.* **20**(21), 1808–1810 (2008).
4. D. Smith, I. Lealman, X. Chen, D. Moodie, P. Cannard, J. Dosanjh, L. Rivers, C. Ford, R. Cronin, T. Kerr, L. Johnston, R. Waller, R. Firth, A. Borghesani, R. Wyatt, and A. Poustie, "Colourless 10Gb/s reflective SOA-EAM with low polarization sensitivity for long-reach DWDM-PON networks," in *European Conference and Exhibition on Optical Communication (ECOC)*, (2009), Paper 8.6.3.
5. H.-S. Kim, D. C. Kim, K.-S. Kim, B.-S. Choi, and O.-K. Kwon, "10.7 Gb/s reflective electroabsorption modulator monolithically integrated with semiconductor optical amplifier for colorless WDM-PON," *Opt. Express* **18**(22), 23324–23330 (2010).
6. D. C. Kim, H.-S. Kim, K. S. Kim, B.-S. Choi, J.-S. Jeong, and O.-K. Kwon, "10 Gbps SOA-REAM using monolithic integration of planar buried-heterostructure SOA with deep-ridge waveguide EA Modulator for colourless optical source in WDM-PON," in *European Conference and Exhibition on Optical Communication (ECOC)*, (2011), Paper Tu.5.LeSaleve.5.
7. G. Talli, D. Cotter, and P. D. Townsend, "Rayleigh backscattering impairments in access networks with centralised light source," *Electron. Lett.* **42**(15), 877–878 (2006).
8. M. Fujiwara, Jun-ichi Kani, H. Suzuki, and K. Iwatsuki, "Impact of backreflection on upstream transmission in WDM single-fiber loopback access networks," *J. Lightwave Technol.* **24**(2), 740–746 (2006).
9. E. MacHale, G. Talli, C. Chow, and P. Townsend, "Reduction of signal-induced Rayleigh noise in a 10 Gb/s WDM-PON using a gain-saturated SOA," in *European Conference and Exhibition on Optical Communication (ECOC)*, (2007), Paper We.7.6.3.
10. P. J. Urban, A. M. J. Koonen, G. D. Khoe, and H. de Waardt, "Interferometric crosstalk reduction in an RSOA-based WDM passive optical network," *J. Lightwave Technol.* **27**(22), 4943–4953 (2009).
11. M. Fujiwara, Jun-ichi Kani, H. Suzuki, and K. Iwatsuki, "Impact of backreflection on upstream transmission in WDM single-fiber loopback access networks," *J. Lightwave Technol.* **24**(2), 740–746 (2006).
12. J. S. Jeong and C.-H. Lee, "Optical noise suppression techniques for wavelength-locked Fabry-Perot laser diode (Invited Paper)," in *Asia-Pacific Conference on Communications (APCC)*, (2009), 592–596.
13. A. D. McCoy, P. Horak, B. C. Thomsen, M. Ibsen, and D. J. Richardson, "Noise suppression of incoherent light using a gain-saturated SOA," *J. Lightwave Technol.* **23**(8), 2399–2409 (2005).
14. G. P. Agrawal, *Fiber-Optics Communication Systems* 3rd ed. (Wiley-Interscience, 2002).
15. A. Chiuchiarelli, M. Presi, R. Proietti, G. Contestabile, P. Choudhury, L. Giorgi, and E. Ciaramella, "Enhancing resilience to Rayleigh crosstalk by means of line coding and electrical filtering," *IEEE Photon. Technol. Lett.* **22**(2), 85–87 (2010).

1. Introduction

The bandwidth demanded for the high-quality multimedia services and the trend of service convergence continues to increase so that is expected to be reached the data-rate of 10-Gb/s per subscriber even in the access network [1, 2]. Dense wavelength division multiplexing (DWDM) technology is considered as the most effective approach to provide the guaranteed bandwidth of 10-Gb/s or higher and to accommodate the large channel number. Recently, the reflective electroabsorption modulator monolithically integrated with semiconductor optical amplifier (REAM-SOA) has been extensively investigated to realise the high capacity system of high speed, long reach, and many channels in the bidirectional DWDM networks with the single-feeder fiber [3–6]. In particular, the REAM-SOA can provide many advantages such as low cost, low power-consumption, simplicity, and easy management for the colorless optical network unit (ONU) of DWDM applications in comparison with the tunable laser diode to require the temperature-control equipment for the wavelength tuning. However, the ONU consisting of a reflective modulator such as the REAM-SOA or the reflective semiconductor optical amplifier (RSOA) heavily suffers from the intrinsic interference noise coming from Rayleigh back-scattered (RBS) light and back-reflection lights by the optical feeder fiber, optical components, connectors, and splices when using the external coherent seed light [7–10]. Many approaches have been suggested to overcome the impairments by RBS light. Fujiwara *et al.* reported the optimal gain conditions of ONU with RSOA in order to reduce the impact of back-reflection on upstream transmission [8]. Also the mitigation of Rayleigh-crosstalk impairments was performed by various techniques such as the in-line SOA operated in saturation region [9], the phase modulation of external seed light, and the bias-current dithering at frequency higher than the bit-rate [10]. Although the incoherent light as the seed-light source can considerably mitigate the drawbacks resulted from the coherent interferences, it is not applicable to WDM network with high speed of about 10-Gb/s due to the intensity noise of incoherent light [11]. In order to increase the power budget in the seeded DWDM system employing the centralized light source, it is extremely important to find out an effective solution to significantly increase the tolerance for RBS light.

In this paper, we introduce an approach to mitigate the degradation by RBS light in 10-Gb/s ONU with the REAM-SOA, which is based on the noise suppression technique of centralized incoherent light source [12, 13]. The EDFA-based incoherent light is spectrum-sliced by the optical filter with 3-dB bandwidth of 0.4 nm and then the intensity noise is suppressed by two cascaded RSOA's at the central office. It provides the large tolerance for RBS crosstalk and the sufficient link budget for the long-reach network without the modification of the transmitter and the receiver. We experimentally exhibit the power penalty of less than 1 dB even at the large RBS crosstalk level of about 8 dB when the seed-light power is lowered about -10 dBm.

2. Experiment

Figure 1 shows an experimental setup to realize the intensity-noise suppression of centralized incoherent seed light and to evaluate the impact of RBS crosstalk in the 10-Gb/s ONU transmitter exploiting the REAM-SOA. The structure of REAM-SOA was monolithically integrated by the buried heterostructure (BH) SOA of 500 μm length and the deep-ridge EAM of 100 μm length [6]. The front-facet reflectivity of REAM-SOA is about 10^{-5} by anti-reflection (AR) coating and the back-facet reflectivity of them is about 90% by high-reflection (HR) coating, respectively. We employed the EDFA-based incoherent light as the seed light source, which was spectrum-sliced by the optical filter 1 (OF1) with Gaussian shape

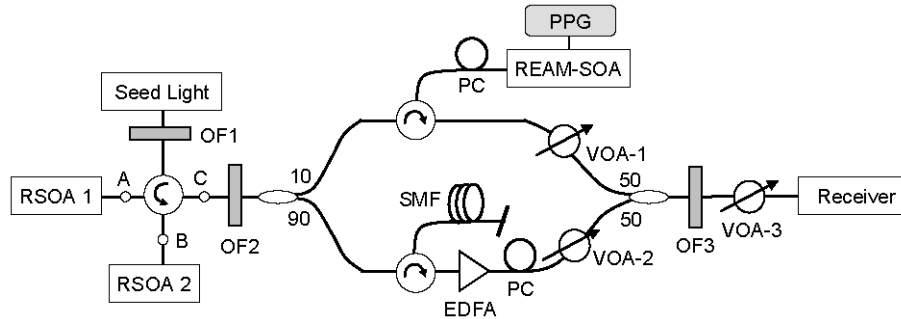


Fig. 1. Experimental setup to evaluate the impact of RBS crosstalk in 10-Gb/s REAM-SOA.

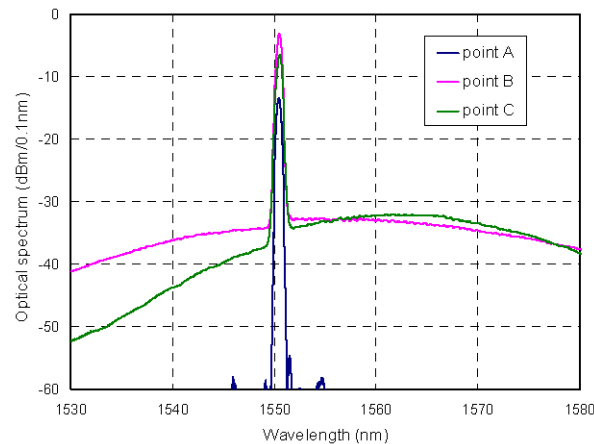


Fig. 2. Optical spectra of incoherent seed light at three different points A, B, and C, as specified in Fig. 1.

and 3-dB bandwidth of 0.4 nm. The intensity noise of spectrum-sliced incoherent light was suppressed by two cascaded RSOA's, which are connected by the 4-port optical circulator (OC). Although two RSOA's and the optical circulator are required per each ONU in the experimental setup of Fig. 1, the monolithically-integrated RSOA array and the schematic to share the optical circulator, shown in Ref [12], can practically lower the increment of system cost for the realization of noise-suppression technique. Also since the noise-suppression technique is performed for the incoherent light at the optical line terminal (OLT), it enables smooth upgrade without modifying the outside plant of the deployed 1.25-Gb/s DWDM applications using the centralized incoherent seed-light [12]. The RSOA with 600 μm -long BH waveguide was AR/HR-coated similarly with the REAM-SOA. The noise-suppressed seed light was split into two paths by a 10/90 coupler after passing through the OF2 with 3-dB bandwidth of 0.9 nm. One portion of the seed-light power was injected into REAM-SOA in order to produce the optical signal. The other portion was utilized to generate the Rayleigh back-scattered noise with using the 3-port OC, 35-km-long single-mode fiber, and EDFA. The optical signal and the RBS light were combined by a 50/50 coupler and then generate the optical interference noise. The interference noise was maximized by adjusting the polarization controller (PC) in RBS path. In the experimental setup, we employed the receiver using the avalanche photodiode (APD). The interfered optical signal was detected by the APD receiver optimized for 10-Gb/s operation, after elimination of the spectrum on the outside of the signal wavelength by the OF3 with 3-dB bandwidth of 0.9 nm. The REAM-SOA at the transmitter was modulated at 10-Gb/s data rate with pseudorandom bit sequence $2^{31}-1$.

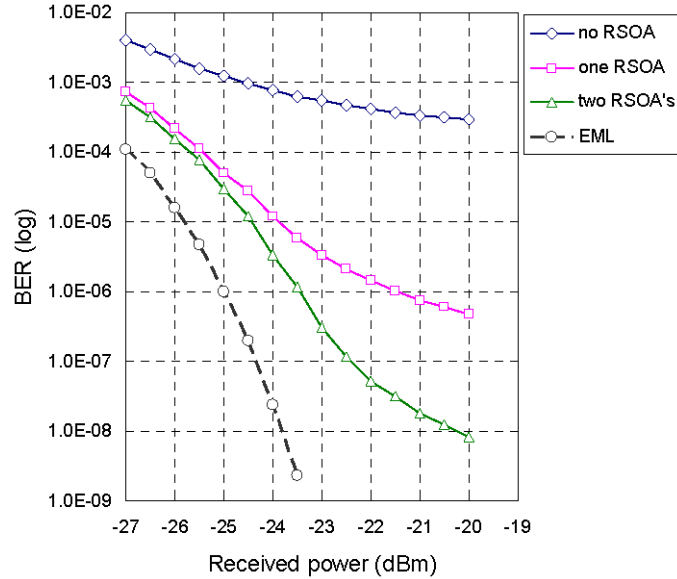


Fig. 3. BER performances of 10-Gb/s REAM-SOA when using three different incoherent lights.

Figure 2 shows the optical spectra of the incoherent seed light at three different points A, B, and C, which are denoted in Fig. 1. The curve at the point A indicates the optical spectrum of the incoherent seed light spectrum-sliced by the optical filter, which has the Gaussian shape with 3-dB bandwidth of 0.4 nm. And we can observe the incoherent seed light after amplification by the RSOA 1 at the point B and after amplification by both of RSOA 1 and RSOA 2 at the point C, respectively. The optical powers launched into the RSOA 1 and the RSOA 2 were controlled about -6.2 dBm and 4.4 dBm. The operating currents of RSOA 1 and RSOA 2 were about 100 mA and 70 mA, respectively. The cascaded RSOA 1 and RSOA 2 perform the amplification and noise-suppression of the spectrum-sliced seed light.

Figure 3 shows the BER performances of 10-Gb/s REAM-SOA for three different incoherent lights: (a) before the noise suppression, (b) after the noise suppression by the RSOA 1, and (c) after noise suppression by the cascaded RSOA 1 and RSOA 2. The seed-light power was fixed into -10 dBm for three incoherent lights. DC bias voltage and peak-to-peak RF voltage of REAM-SOA were fixed to -0.6 V and 2.0 V, respectively. And the bias current of SOA at REAM-SOA was set about 40 mA. The operating conditions produced the optical signal with the output power of about -3 dBm and the extinction ratio of about 12 dB. The BER curves exhibit the error-floor level of about 3×10^{-4} before the noise suppression, about 5×10^{-7} after the noise suppression by one RSOA, and about 8×10^{-9} after the noise suppression by two cascaded RSOA's. According to the measured results, it is found that the BER performance is improved about 6×10^2 times with the noise-suppression by the RSOA 1 and about 3.8×10^4 times by two cascaded RSOA's. And theoretically [14], when using the receiver with the optimum decision level and the electrical bandwidth of 7.5-GHz, the BER values of 3×10^{-4} and 8×10^{-9} are resulted from the relative intensity noise (RIN) levels of about -111.6 dB/Hz and -116.3 dB/Hz, respectively. Also the optical signal with high RIN level gives rise to the degradation of the BER performance, which is observed in the comparison with the back-to-back BER curve, shown in Fig. 3, by the externally modulated laser (EML) with the extinction ratio of about 12 dB instead of the REAM-SOA.

Figure 4 illustrates the variation of BER curves for several RBS crosstalk values when the noise of seed light is suppressed by two cascaded RSOA's. The operation conditions of REAM-SOA are the same with Fig. 3. According to the measured BER curves, the RBS

crossstalk gives a large influence on both the power penalty and the error-floor level even if the

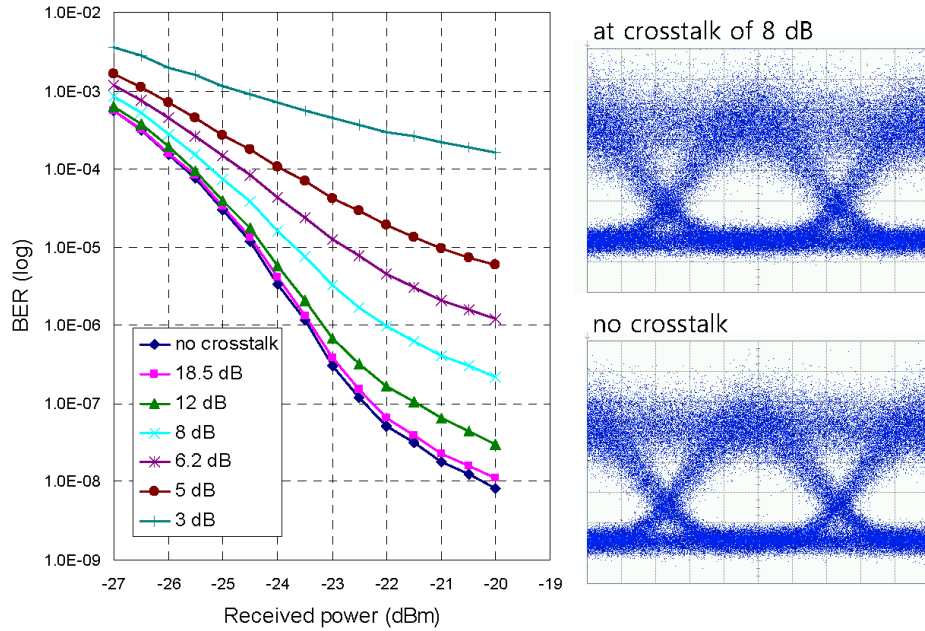


Fig. 4. BER performances and eye diagrams for several RBS crosstalk.

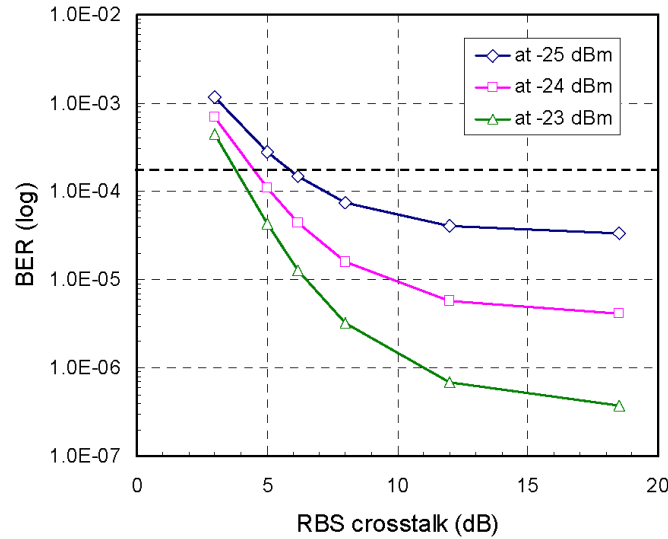


Fig. 5. Variation of BER level as a function of RBS crosstalk.

incoherent seed light is employed. However, we can find that the BER performance is almost not distorted by up to the RBS crosstalk level of 18.5 dB, whereas the coherent seed light normally gives rise to a severe power penalty of higher than 5 dB in the similar RBS crosstalk level [15]. In addition, we can obtain the power penalty of less than 1 dB at BER of 10^{-5} for the large RBS crosstalk of about 8 dB. In Fig. 4, we compared the optical eye diagrams between the no RBS crosstalk and the RBS crosstalk of 8 dB. In the eye diagram with the RBS crosstalk of 8 dB, it can be seen that the eye opening is weakly degraded. Meanwhile, if

considering the forward-error correction (FEC) code with the FEC threshold of 1.8×10^{-4} [16], we can achieve the error-free performance even under the RBS crosstalk of greater than 8 dB. Meanwhile, since the intrinsic RBS light by the optical feeder fiber is not taken place in the downstream transmission, the amount of reflection lights in the downstream signal is considerably smaller than that of reflection lights in the upstream signal. As a result, the noise-suppression scheme of the incoherent seed-light in the downstream transmission could be achieved by just one RSOA.

Finally, Fig. 5 depicts the variation of BER level as a function of RBS crosstalk at three different received powers. The dashed line indicates the FEC threshold of 1.8×10^{-4} . The BER levels are almost not changed until the RBS crosstalk is arrived at 12 dB. However, if the RBS crosstalk is increased into the large level of higher than 12 dB, the BER levels are significantly increased. As a result, the RBS crosstalk values for the BER level of 1.8×10^{-4} are permitted up to about 6 dB at the received power of -25 dBm, 4.4 dB at -24 dBm, and 3.7 dB at -23 dBm, respectively. The received power of -25 dBm provides the power budget of about 22 dB since the optical signal power of REAM-SOA is about -3 dBm.

3. Conclusion

We have demonstrated the mitigation of RBS impact by using the intensity-noise suppression of the incoherent seed light in 10-Gb/s REAM-SOA. The noise suppression has been achieved by two cascaded RSOA's located at the OLT, which enables smooth upgrade of deployed DWDM applications without modifying the outside plant. Through the noise-suppression technique, we have found that the error-floor level of BER curve is significantly lowered from BER of 3×10^{-4} into BER of 8×10^{-9} and the power penalty is reduced about less than 1 dB at the large RBS crosstalk of 8 dB when the seed-light power is considerably decreased about -10 dBm. Also it is notable that the RBS-crosstalk value of about 6 dB corresponds to the FEC threshold of 1.8×10^{-4} at the received power of -25 dBm. It implies that the noise-suppression technique is useful to the long-reach network with data-rate of 10-Gb/s or higher when considering the communication system employing the FEC code.

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